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BASIC PHYSICAL APPLICATIONS AND THE MATHEMATICAL DEVELOPMENT OF A GLINT VISUAL THRESHOLD DOMAIN MODEL

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This paper discusses a theory that deals with discerning the basic physical concepts involved in the attenuation of the glint spectral energy signature transmitted along two optical paths defined as a) sun to ground reflecting surface to observer, and b) sun to background reflecting surface to observer. This approach will provide a basis for developing a mathematical model that calculates a locus of points that define a glint visual threshold domain, based on a range of specular surface reflectivity coefficients associated with a corresponding range of solar incident angles. Modifications to the values of the surface reflectivity coefficients due to changes in the optical properties of the specular surface will result in a corresponding change in the glint threshold domain definition. Thus, this model can serve as a decision-aid tool for designing specular surfaces.

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BASIC PHYSICAL APPLICATIONS AND THE MATHEMATICAL DEVELOPMENT OF A GLINT THRESHOLD VISUAL DOMAIN MODEL

1 APPLICATION THEORY FOR MODEL

The following theory deals with discerning the basic physical concepts involved in the attenuation of the glint spectral energy signature transmitted along two optical paths defined as a) sun to ground reflecting surface to observer and b) sun to background reflecting surface to observer. This approach will provide a basis for developing a mathematical model that calculates a locus of points that define a glint visual threshold domain, based on a range of specular surface reflectivity coefficients associated with a corresponding range of solar incident angles (Figures 1 and 2). Modifications to the values of the surface reflectivity coefficients due to changes in the optical properties of the specular surface will result with a corresponding change in the glint threshold domain definition. Thus, this model can serve as a decision-aid tool for designing specular surfaces.

The attenuation effects on transmitted solar energy along the optical paths within the 0.4 - 0.7 μm visual wavelength region will be discussed in terms of atmospheric extinction, surface reflective geometries and detector response. Reflectivity properties of a specular surface will be presented as an attenuation function that is wavelength and solar incidence angle dependent. The application of spectrally resolved and integrated concepts, using the contrast ratio of the glint-to-background spectral intensity values at various distances from the reflecting source, will be considered since contrast ratio quantification is independent of solar variation intensity.

The eye is considered as the visual response filter because we are concerned about human visual response to photo-spectral stimuli, although any detector response filter can be considered as a response filter in this model. Since psychological stimuli and responses are involved when visually interpreting, it is necessary to look at the photometric response of the eye to the radiant flux density transmitted from a reflecting source to the observer as a spectrally integrated weighting function. Narrow band pass or single visual wavelength filtering will be addressed as a spectrally resolved approach to viewing glint visual signatures.

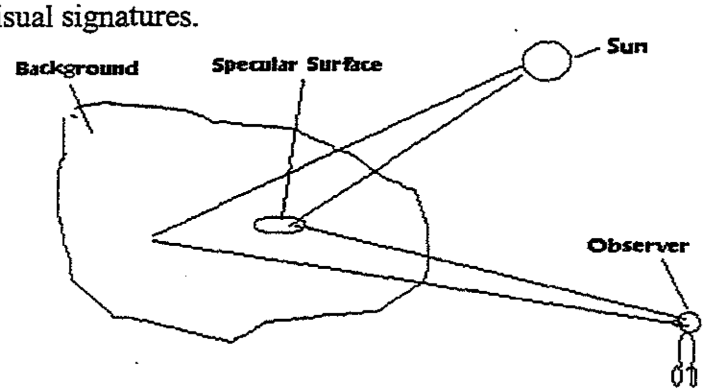

Figure 1. Sun to Specular Surface and Background Optical Paths

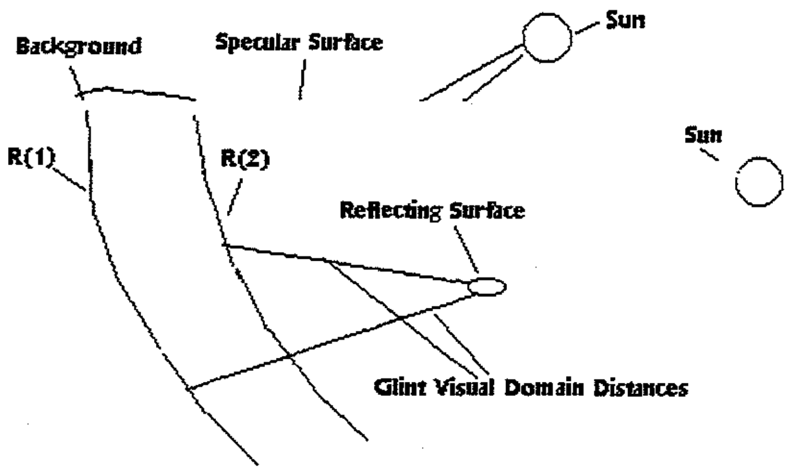

Figure 2. Pictorial of Glint Visual Threshold Domains Based on Two Sets of Specular Surface Reflectivity Coefficients R(1) and R(2), Wavelength and Solar Incidence Angle Dependent

1.1 PHYSICAL CONCEPT APPLICATIONS

1.1.1 RADIOMETRIC AND PHOTOMETRIC DEFINITIONS

When undertaking the study of radiometry and photometry, we assume the existence of an instrument called a radiometer. If radiant energy is incident upon a radiometric response surface of known area and orientation relative to its direction, then radiant energy is converted to electrical energy in the radiometer as a stimulus response reaction. In the same context, the eye produces a bio-metric stimulus response reaction to radiant energy in the form of a photoelectric conversion to sight.

Radiometric quantities are physical quantities that are expressed in energy and geometrical units. For purposes of this paper the energy and geometric terms will be defined as rate of energy transmitted per unit area, which is called radiant flux density. Thus the units can be expressed as watts/cm^2. The level of radiant flux density will be equated to the level of specular or glint reflection from a mirror-like surface, such as eye armor.

The retina of the eye is a photoelectric receptor. Since perceptual response to physical stimuli is involved, the eye retinal receptor response to the visual wavelength spectrum of 0.38 - 0.74 μm could be better defined as psycho-physical. We are dealing with a photometric response to a radiometric stimuli of solar spectral energy. In this context, light is a visual aspect of radiant energy, of which the human observer is aware through the visual sensations that arise from the stimulation of the retina of the eye. Brightness is defined as that attribute of visual sensation by which an observer is aware of differences of observed radiant energy.

1.1.2 LUMINOUS ENERGY

When the human eye is used as a photoreceptor to the visual spectrum to measure the relative levels of brightness, a relative luminosity curve represented by the function 'V(λ)'

light adapted human eye. Generally, to convert the visual spectrum of radiant energy to luminous energy 'Q' according to the spectral energy function 'U_λ', we use the relative luminosity function '$V(\lambda)$' as a weighting function in the following equations:

$$Q = K_M V(\lambda) U_\lambda \qquad (1)$$

or

$$Q = K_M \int_0^\infty V(\lambda) U_\lambda d\lambda \qquad (2)$$

where K_M is a constant that determines the units for Q. This equation provides the bridge to convert radiometric to photometric units. The photopic spectral luminosity $V(\lambda)$ of the human eye as a function of the wavelength of radiant energy* is depicted in Figure 3.

1.1.2.1 LIMINAL CONTRAST RATIOS

A highly developed sensitivity of the eye is its ability to detect a small difference in luminance. This difference is called contrast sensitivity or liminal contrast. Contrast 'C' for a given set of conditions is defined as,

$$C = (L_B - L_0)/L_A \qquad (3)$$

where 'L_0' and 'L_B' are the object's or reflecting surface's and background luminances respectively. The luminance to which the eye is adapted is 'L_A'. When the reflecting object and background fill the field of view of the eye, 'L_A' is determined by 'L_0' and 'L_B'. When the reflecting object and background illuminated areas are approximately equal in size, then, $L_A \cong 1/2(L_B + L_0)$. (4)

If the size of the reflecting or luminous object is small compared to that of the background, which is true regarding the eye armor reflecting surface to background size ratios, then the eye adaptation response approximates the background illumination

$$L_A \cong L_B. \qquad (5)$$

* Erickson, Ronald, China Lake Report: "Visual Detection of Targets", China Lake, 1965

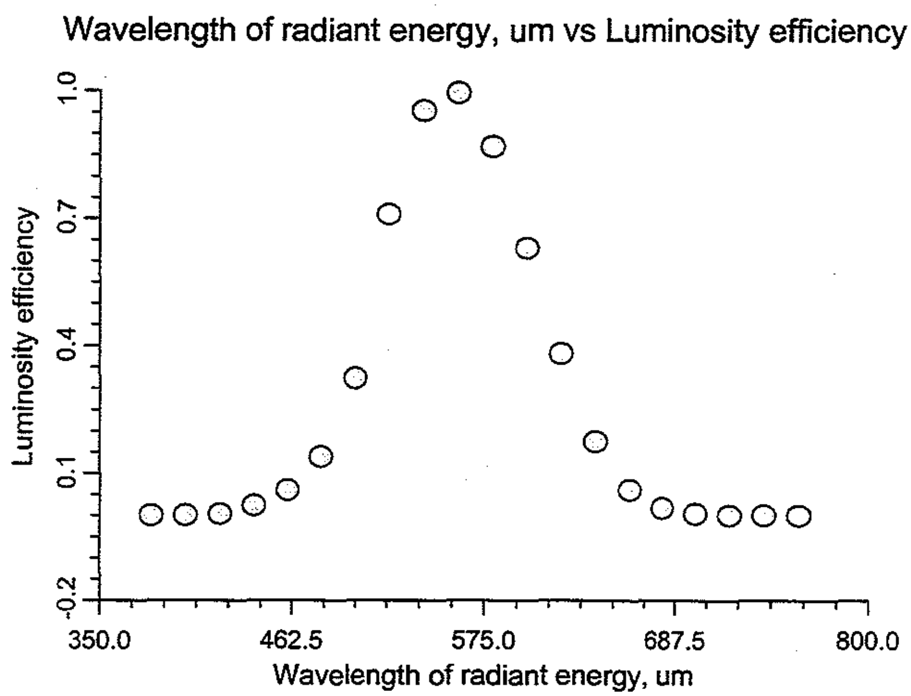

Figure 3. Spectral Response of Eye

1.1.3 EMISSIVITY, REFLECTANCE, ABSORPTANCE, TRANSMITTANCE

Emission, reflection, absorption, and transmission of radiant (solar-spectral) energy are often treated as surface phenomena. In reality, these phenomena exist when radiant energy interacts with a surface of any physical body. A true blackbody, by definition, absorbs all incident radiant energy. However, a non-blackbody is defined as having an absorbtance ratio '$\alpha(\lambda)$' of the absorbed to incident energy with a value less than unity. This means that the balance of the energy is reflected and transmitted.

Let us assume that a non-blackbody reflecting object having an absorptance '$\alpha(\lambda)$' less than unity, is placed within an ideal blackbody cavity. According to the principles of thermodynamics, the object will reach the temperature 'T' of the cavity and remain at this temperature. At this equilibrium condition, the spectral irradiance at the object surface is equal to the spectral emitted radiance '$M_\lambda(T)$' derived from Planck's Radiation Law as the energy flow rate per wavelength per unit area of a blackbody surface. Yet the power absorbed by the object will equal '$\alpha(\lambda)M_\lambda(T)$'. The remaining power must be apportioned to transmission and reflection. If the object is assumed opaque, the amount reflected can be quantified using the expression $[1 - \alpha(\lambda)]M_\lambda(T)$. Because an object is generally in equilibrium with its surroundings, it must emit as much energy as it absorbs '$\alpha(\lambda)M_\lambda(T)$' to satisfy Kirchhoff's law. Emissivity '$\varepsilon(\lambda)$' is defined as the ratio of the energy emitted by the surface compared to the energy emitted by an equal area of a blackbody surface at the same temperature.

At the surface of an object where radiant energy at wavelength 'λ' is incident upon the surface, a fraction '$\alpha(\lambda)$' is absorbed, a fraction '$\rho(\lambda)$' is reflected, and a fraction '$\tau(\lambda)$' is

transmitted. For most materials, the radiant absorbing value '$\alpha(\lambda)$' is almost constant with change in incidence angle. But the wavelength dependent reflecting and transmitting radiant energy rates per unit area will change with incidence angle, based on the nature of the optical characteristics of the materials. Because energy must be conserved we have:

$$\alpha(\lambda) + \rho(\lambda) + \tau(\lambda) = 1. \qquad (6)$$

The reflection may occur at the surface by either specular (glint) or diffuse reflection, or it may return from within the material by scattering if the material is a translucent, non-homogeneous medium.

In summary, the incident, reflected, and emitted energy must be considered external to the object surface. Internal to the object surface, there is absorbed, transmitted, and scattered energy.

1.1.4 ATMOSPHERIC EXTINCTION EFFECTS

There are three atmospheric processes responsible for the attenuation of transmitted optical images and electro-optical energy such as solar glint. They are 1) aerosol extinction, 2) molecular absorption, and 3) turbulent distortion (scintillation and beam wander). Light propagating through the atmosphere is not only scattered and absorbed by aerosols and molecules, but the wave fronts are deflected and distorted by turbulence.

The extinction has several components: molecular scattering and absorption [$j(\lambda)=j_1(\lambda)+j_2(\lambda)$] and aerosol scattering and absorption [$l(\lambda)=l_1(\lambda)+l_2(\lambda)$]. The extinction parameter values correlate to the loss of light energy as it is scattered out of the beam or absorbed by the molecule and particulate constituents of the atmosphere during transmission. A combination of Bouguer's and Beer's laws can theoretically quantify the level of absorption of transmitted radiant energy '$\Phi(\lambda)$' over a distance 'R_0' based on the nature of the absorption and scattering medium [$k(\lambda)=j(\lambda)+l(\lambda)$] and wavelength of the original transmitted energy '$\Phi_0(\lambda)$' using the following expression,

$$\Phi(\lambda) = \Phi_0(\lambda) \exp[-k(\lambda)R_0]. \qquad (7)$$

The distortion and tilt of image wave fronts by atmospheric turbulence is represented by 'C^2_N'. We can write 'C^2_N' as a function of temperature 'C^2_T' and water vapor '(C^2_Q)' turbulence parameters as follows:

$$C^2_N = (79\text{x}10^{-6}P/T^2)^2(C^2_T + 0.113\ C_{TQ} + 3.2\text{x}10^{-3}\ C^2_Q) \qquad (8)$$

where 'P' is the pressure in millibars, 'T' the absolute temperature, and 'C_{TQ}' the temperature humidity co-spectral structure function parameter. The refractive index parameter 'C^2_N' can be derived in three ways: 1) optical measurement, 2) measurement of 'C^2_T', 'C_{TQ}' and 'C^2_Q', and 3) calculation of 'C^2_T', 'C_{TQ}' and 'C^2_Q' from bulk meteorological data made up of water temperature, air temperature, humidity and wind speed.

The total extinction ($\alpha + \beta$) can be measured optically by determining the reduction in beam intensity over some suitable optical path. The separate components can be calculated from meteorological data. The molecular extinction values can be extracted from a LOWTRAN model and database developed by the Air Force Geophysics Laboratory (Selby et al., 1978). The aerosol extinction can be calculated from the aerosol spectral density 'N(r)', as follows;

$$\alpha = \int_0^{\infty} 2\pi r^2 \, E(n,\lambda) \, N(r) \, dr \qquad (9)$$

where r is the particle radius, $E(n,\lambda)$, the total scattering efficiency at wavelength 'λ' and refractive index 'n'.

1.2 GLINT CONTRAST RATIO MODEL DEVELOPMENT

1.2.1 BACKGROUND

The application of an imaging detector, i.e., eye, Charged Coupled Device (CCD), etc., as a device for taking glint and background reflection measurements at various distances from a specular reflecting source provides a good field trial approach towards the verification of existing contrast ratio models* that use spectrally resolved and integrated applications. The delta between experimental and model projected contrast ratios over a distance from a reflecting source could be significantly influenced if the model neglects to consider the factor influences of a) ground level atmospheric extinction on solar energy propagation and b) the effects of the optical surface's reflection coefficients on the level of solar spectral energy reflecting from a surface as a function of incidence/reflection angle and wavelength.

The model assumes the glint reflection viewed by an observer is a point source and the background an extended object. The point source application assumes that the spectral intensity decreases as an inverse square of distance. Glint to background spectrally resolved contrast ratios are independent of changes in solar brightness since the glint and background components change simultaneously.

The United Kingdom's Defence Evaluation Research Agency developed a visual glint contrast ratio model to calculate glint contrast ratios over distances from ground reflecting sources and uses these results to feed into their detection time model.

1.2.2 SPECTRALLY RESOLVED RELATIVE INTENSITY

To derive the representative expression for spectrally resolved relative intensity we need to develop the relationships that describe the glint intensity viewed from a reflecting surface and from a background.

* RI Young, RC Hollins, T Holloway "Simple Model for Predicting Glint to Background Contrast Ratios, Optical Glint Studies US and U.K. Joint Venture", DERA, U.K., July 1997

1.2.2.1 REFLECTING SURFACE TO OBSERVER

Assume the goggles' curved surface have radius 'r' such that its focal length is 'r/2'. The goggles will reflect sunlight into a diverging cone of half angle (D/2)/(r/2) = (D/r), where 'D' equals cone diameter at the reflecting surface. This means that the reflected cone at range 'R_0' has a radius of: $(R_0)(D/r)$.

Let the glint reflection intensity from a goggle surface $I_{gog}(\lambda) = I_0(\lambda,\alpha)R_c(\lambda,\alpha)$ where: solar intensity function is $I_0(\lambda,\alpha)$, and incident to goggle surface at angle (α), and at visual wavelength (λ). Also, the goggle reflectivity coefficient function is $R_c(\lambda,\alpha)$ at visual wavelength (λ) and incident angle (α). Then, the reflected power/unit area at range 'R_0' is defined as follows:

$$I_{gog} \text{ at } R_0 = \text{power/unit area} = [I_0(\lambda,\alpha)R_c(\lambda,\alpha)\pi D^2/4\,]/\,[\pi R_0^{\,2}/r^2] = I_{gog}(\lambda)r^2\,/\,4R_0^{\,2} \quad (10)$$

Now the sensor receives power over detector area 'A_d' but lacks the angular resolution to form a proper image of glint. Thus glint appears as a feature of the detector angular width 'θ_d' resolution. Since the perceived glint intensity as seen by the detector is equivalent to the received power divided by the angular width squared, then the perceived glint intensity at detector can be defined as 'I_{gd}'. The detector glint intensity level can now be expressed as:

$$I_{gd}(\lambda) = I_{gog}(\lambda)r^2A_d\,/\,4\theta_d^{\,2}R_0^{\,2} \qquad (11)$$

which depends on angular resolution 'θ_d' of the sensor. Since point source theory is applied, the intensity relates inversely to the square of the range or distance 'R' from reflecting source to detector.

1.2.2.2 BACKGROUND TO OBSERVER

The background intensity '$I_b(\lambda)$' reflects with diffuse reflectance '$\rho_b(\lambda)$' times incident solar intensity $I_0(\lambda)$ into a hemisphere over a '2π' angle. From a background of area 'A_b', the reflected intensity at range R_0 is

$$I_b(\lambda) \text{ at } R_0 = A_bI_0(\lambda)\rho_b(\lambda)/2\pi\,R_0^{\,2} = A_bI_b(\lambda)/2\pi R_0^{\,2}. \qquad (12)$$

The power received by the sensor is $(A_d)(I_b)$ where the perceived detector area is defined by A_d. Since the background area 'A_b' is sufficiently large for a detector sensor to form a properly resolved image of angular size $(A^{0.5})/\,R_0$, then the detector perceived background intensity 'I_{bd}' can be expressed as perceived power divided by the angular width squared.

$$I_{bd}(\lambda) = [R_0^{\,2}/A_b]\,A_dA_b\,I_b(\lambda)\,/\,2\pi\,R_0^{\,2} = I_b(\lambda)A_d/2\pi \qquad (13)$$

Thus the perceived intensity of the background by a detector is independent of its angular resolution and the range between background and reflecting source, given the assumption that the diffusion reflection has a '2π' angular domain due to a flat background.

1.2.2.3 CONTRAST RATIO (GLINT/BACKGROUND)

We can now define the intensity of glint relative to the background as perceived by the detector, in terms of spectrally resolved relative intensity, by solving for the contrast ratio '$C_R(\lambda)$' of the previously derived expressions of glint and background reflections 'I_{gd}, I_{bd}'

$$C_R(\lambda) = [I_{gd}(\lambda)/I_{bd}(\lambda)] = [I_{gog}(\lambda)/I_b(\lambda)](\pi r^2) / [2\theta_d{}^2 R_0{}^2]. \qquad (14)$$

This spectrally resolved contrast ratio expression is independent of solar intensity but depends on angular resolution of detector source, distance from reflecting source, and optical reflection characteristics of background and reflecting surface. The contrast ratio calculated over distance is based on the inverse square law.

1.2.3 SPECTRALLY INTEGRATED RELATIVE INTENSITY

Let us consider the spectrally integrated relative intensity as perceived by a detector with a spectral response function '$f(\lambda)$'. The spectrally integrated contrast ratio 'C_I' can be expressed by combining the spectrally resolved expression '$C_R(\lambda)$' from the previous section with the integral expressions of a) solar spectral energy incident to background and glint surface '$I_0(\lambda,)$', b) background and surface reflectivity filter or weighting functions '$R_b(\lambda)$ and $R_c(\lambda,\alpha)$' and c) spectral response function of the detector '$f(\lambda)$'.

Thus the resulting expression is

$$C_I = \left[\frac{\int I_0(\lambda,)R_c(\lambda,\alpha)f(\lambda)d\lambda}{\int I_0(\lambda)\rho_b(\lambda)\, f(\lambda)d\lambda} \right](\pi r^2) / [2\theta_d{}^2 R_0{}^2]. \qquad (16)$$

This is a useful model for ocular (eye) detection. However, the model is sensitive to solar spectral shifts caused by changes in the optical path of sunlight due to the solar elevation angle coupled with the atmospheric extinction effects.

Further analyzing equation (16), the average integral of $I_0(\lambda) = \int K_M V(\lambda) U_\lambda d\lambda$ is equivalent to equation (2). Based on the application of empirical data statistical curve fitting techniques, the solar zenith and smooth surface reflectivity coefficient functions highly correlate with the respective solar elevation and solar incidence to surface span of angles using a 5th degree polynomial fit done in conjunction with the above average integral equation. The background reflection function '$\rho_b(\lambda)$' is dependent on the nature of the background while the detector filter spectral response function '$f(\lambda)$' is a weighting function whose shape is dependent on the nature of the detector response filter.

1.3 GLINT VISUAL DOMAIN MATHEMATICAL MODEL

The use of a mathematical model for accurately calculating a glint visual domain is significant for designing low reflectivity optical surfaces. This approach is possible by mathematically describing the attenuation of solar glint energy over the defined optical paths. An example is the atmospheric extinction effects on solar energy depicted by the solar relative intensity versus zenith angle graph* in Figure 4.

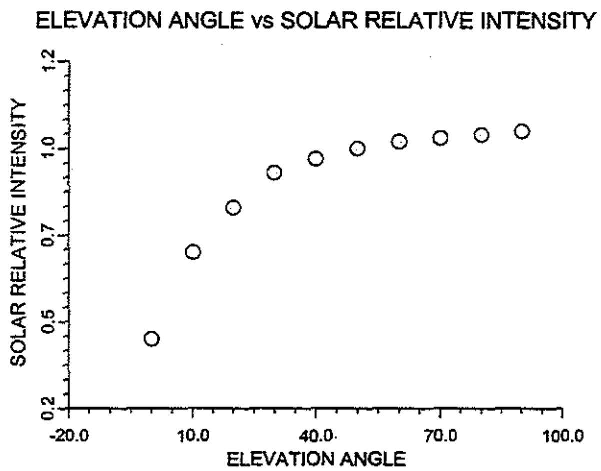

Figure 4: Atmospheric Extinction Effects on Solar Energy

Another attenuation effect results from a reflecting surface interacting with incident solar spectral energy. A general relationship between solar incidence/reflection angle and surface reflectivity coefficients is depicted for a basic eye armor surface in Figure 5.

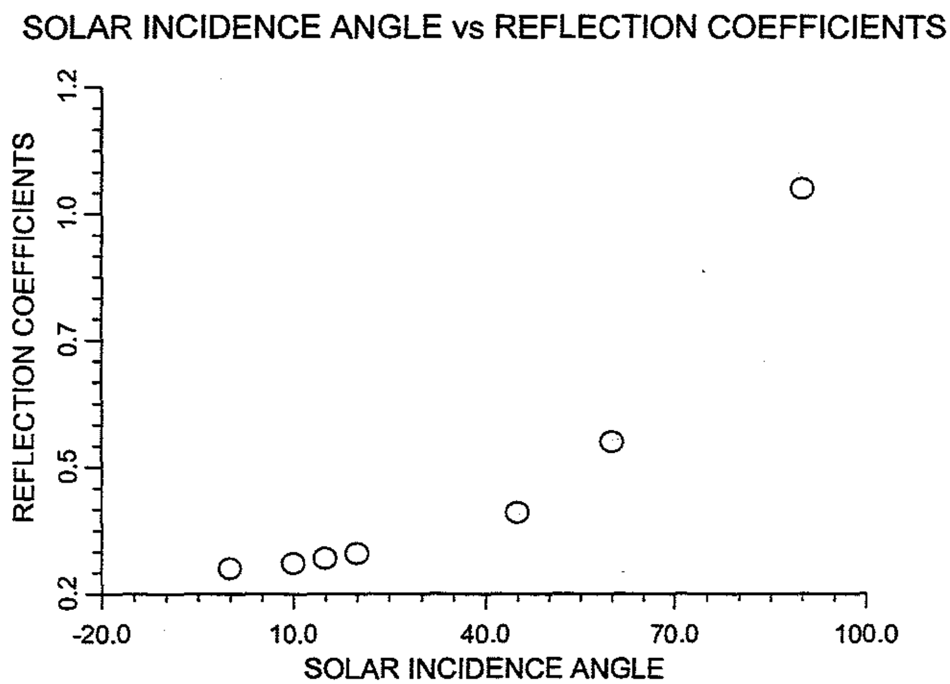

Figure 5: Reflectivity Characteristics of Eye Armor Surface

*Kreith, Frank, Principles of Solar Engineering. Washington, DC, McGraw

The final segment of the optical path is the atmospheric extinction effects on solar spectral energy transmitted to an observer, based on humidity and particulate levels. Atmospheric turbulence effects on transmitted solar energy are not considered. Refer to previous section 1.1.4: 'ATMOSPHERIC EXTINCTION EFFECTS' for details.

The spectrally resolved and integrated contrast ratio expressions developed in the previous sections 1.2.2.3 and 1.2.3 will be expanded to include the effects of a) solar zenith angle function, b) surface and background reflectivity coefficient functions, and c) atmospheric extinction absorption and scattering effects.

1.3.1 SPECTRALLY RESOLVED APPROACH

The spectrally resolved contrast ratio expression can now be expressed as follows;

$$C_R(\lambda) = [I_{gd}(\lambda)/I_{bd}(\lambda)] = \frac{[I_0(\lambda)Z_c(\lambda,\beta)R_c(\lambda,\alpha)]\{\exp[-k(\lambda)R_0]\}(\pi r^2)}{[I_0(\lambda)\rho_b(\lambda)][2\theta_d^2 R_0^2]} \qquad (18)$$

where:
- $C_R(\lambda)$ = contrast ratio (wavelength dependent)
- $I_{gd}(\lambda)$ = goggles reflected solar intensity incident to detector
- $I_{bd}(\lambda)$ = background reflected solar intensity incident to detector
- $I_0(\lambda)$ = zenith solar intensity incident to background and reflecting surface
- $Z_c(\lambda,\beta)$ = solar zenith angle coefficient function (wavelength and zenith angle(β) dependent)
- $R_c(\lambda,\alpha)$ = normalized surface reflectivity function (wavelength and incident angle(α) dependent)
- $\rho_b(\lambda)$ = background diffuse solar reflectivity function
- $I_0(\lambda)\rho_b(\lambda) = I_b(\lambda)$ reflected background solar intensity
- $k(\lambda)$ = atmosphere total extinction coefficient
- R_0 = distance or range observer from glint reflecting source
- r = radius of curvature of goggles (gently sloping)
- θ_d = angular resolution or spread of detecting source

By mathematically solving for 'R_0' of equation (18), we get

$$R_0 = (r/\theta_d)\{[I_0(\lambda)Z_c(\lambda,\alpha)R_c(\lambda,\alpha)/I_b(\lambda)]\{\exp[-k(\lambda)R_0]\}\pi /2C(\lambda)\}^{0.5}. \qquad (19)$$

By arbitrarily setting values of the following parameters as follows: a) the threshold contrast ratio '$C_R(\lambda)$' to 1.2, b) the extinction coefficient '$k(\lambda)$' to a corresponding level of humidity, c) the solar elevation angle function '$Z_c(\lambda,\alpha)$' to a solar elevation angle, d) the reflectivity function '$R_c(\lambda,\alpha)$' to cover a range of solar incidence to surface angles, and e) the detector angular resolution, a visual domain bounded by a locus of visual threshold points at ground distance R_0 from the reflecting source which can be generated by solving for the range R_0. Empirically fitted polynomial expressions can be used to evaluate the

solar zenith and surface reflectivity coefficients, based on the corresponding solar elevation angle and range of reflecting surface solar incidence angles used.

Changing the reflecting surface's optical characteristics would result in changing the size and shape of the generated visual threshold domain.

On perfectly clear days the extinction coefficient '$k(\lambda)$' approaches zero in value such that the exponential expression has a value of one. If there are varying levels of humidity, then the range R_0 would have to be solved iteratively.

The advantages of using this approach are that the equations more accurately describe the basic physical phenomena of the optical path.

As with the application of any contrast ratio concept, the field trial verifications would be generally independent of the energy intensity level fluctuations but depend on detector source's angular resolution. The intensity decreases as the inverse square of range. Regarding the reflecting surface geometry, the reflecting surface effective radius of curvature is the square root of the product of the radii components.

1.3.2 SPECTRALLY INTEGRATIVE APPROACH

We can use the spectrally integrative approach even though the contrast ratio is sensitive to spectral changes such as diurnal spectral shifts. The expression would be an integral over the 0.4 - 0.7μm eye photo visual region of the solar spectrum of the previous spectrally resolved expression.

It is expressed as;

$$C_I = \left[\frac{\int I_0(\lambda)Z_c(\lambda,\beta)R_c(\lambda,\alpha)f(\lambda)d(\lambda)}{\int I_0(\lambda)Z_c(\lambda,\beta)\rho_b(\lambda)f(\lambda)d(\lambda)}\right]\{\exp[-k(\lambda)R_0]\}(\pi r^2) / [2\theta_d^2 R_0^2] \qquad (20)$$

where:

$I_0(\lambda)$ = zenith solar intensity (wavelength dependent)

$Z_c(\lambda,\beta)$ = solar elevation angle function (wavelength and zenith angle dependent)

$R_c(\lambda,\alpha)$ = surface reflectivity function (wavelength and incident angle dependent)

$\rho(\lambda)$ = background diffuse reflectivity function

$k(\lambda)$ = atmosphere total extinction coefficient

R_0 = distance or range observer from glint reflecting source

r = radius of curvature of goggles (gently sloping)

θ_d = angular resolution or spread of detecting source

$f(\lambda)$ = detector spectral response function

We solve the spectrally integrated expression equation (20) for threshold range or distance R_0 from the reflecting source as we did with the spectrally resolved equation (18).

Values are set for the parameters like we did when using the spectrally resolved equation as follows: a) the threshold contrast ratio '$C_R(\lambda)$' to 1.2, b) the extinction coefficient '$k(\lambda)$' to a corresponding level of humidity, c) the solar elevation angle function '$Z_c(\lambda,\alpha)$' to a solar elevation angle, d) the reflectivity function '$R_c(\lambda,\alpha)$' to cover a range of solar incidence to surface angles, and e) the detector angular resolution.

Regarding optical path evaluation, we integrally average the incident solar spectral energy function at zenith to obtain the solar luminosity incidence value, i.e., 140,000 candles/cm^2. We evaluate the solar zenith angle and surface reflectivity coefficients using the corresponding known and 'empirically fitted' polynomial equations.

The product of the solar zenith incidence energy '$I_0(\lambda)$', solar zenith angle coefficient '$Z_c(\lambda,\beta)$' and the range of surface reflectivity coefficients '$R_c(\lambda,\alpha)$' yield a range of glint surface reflection values 'I_{gog}' that are further attenuated by the atmospheric extinction effects on the glint signature propagated over the distance to observer. The filter weighting function '$f(\lambda)$' and the angular resolution 'θ_d' of the detector determine the detector response to the incoming glint and background energy.

The background spectral energy incoming to the detecting source is the product of the incident to background surface solar spectral energy '$I_0(\lambda)Z_c(\lambda,\beta)$' and the background diffuse reflectivity function '$\rho(\lambda)$' attenuated by the atmospheric extinction effects.

A visual domain bounded by a locus of visual threshold points at ground distance R_0 from reflecting source is generated.

1.3.3 MODEL APPLICATIONS

This model can be converted to a software package and used as an optical surface design tool by allowing the user to evaluate how changes in the optical characteristics of reflecting surfaces will impact on the size and shape of the glint visual threshold domains.

The model accurately interprets the attenuation of transmitted solar energy along its optical path, thus enhancing realism as a decision aid tool for surface design.

1.3.4 FUTURE CONSIDERATIONS

The effects of atmospheric turbulence on glint will be evaluated in the future by modeling gaussian shaped glint noise scintillation modulated to a continuous wave glint signature. There is a potential need to model and verify significant differences in the observer's signature-acquired detection times at a reasonable probability of detection level between gaussian and nongaussian glint signatures at various observer distances from reflecting source. For example, a significant difference surface threshold domain can be generated from a field-generated data base, using statistical fitting techniques, that depicts

statistically viable gaussian and nongaussian detection time differences against glint intensity and glint signal to gaussian spectral noise levels.

A key question that must be answered is "under what combat scenerio circumstances does glint hazard become significant enough to compromise the mission"? If there are circumstances, "what range of significantly different gaussian minus nongaussian glint values located within the threshold contour domain would contribute to the glint hazard".

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LIST OF REFERENCES

1) R.I. Young, R.C. Hollins, T. Holloway; "Simple Model for Predicting Glint to Background Contrast Ratios, Optical Glint Studies US and U.K. Joint Venture", DERA, U.K., July 1997.

2) Schmelz, Mark; "Reflections from the Sun-Wind-Dust Goggles", Natick Labs, 07 May 1990, Natick, Ma.

3) Kreith, Frank; "Principles of Solar Engineering". Washington, DC, McGraw Hill, 1978.

4) Forsythe, William Elmer; Smithsonian Physical Tables, 9th Revised Edition, Washington, D.C., Smithsonian Institution Press, 1956.

5) Erickson, Ronald; "Visual Detection of Targets: Analysis and Review", U.S. Naval Ordnance Test Station, China Lake, CA, 1965 (AD612721).

6) Corson D.R., Lorrain P.; "Introduction to Electromagnetic Fields and Waves", W.H. Freeman and Company, San Francisco and London, 1962.

7) Williams C.S., Bechlund O.A. "A Short Course for Engineers & Scientists", Wiley Inter-Science, New York, 1972.